Copy #6

[redacted]

5 November 1942
~~CONFIDENTIAL~~

NRL Report No. S-1959

NRL1959

NAVY DEPARTMENT

THE

A-B-C'S

of

ANTI-SUBMARINE WARFARE

UNCLASSIFIED

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of pages: Text 13

Prepared by:

Dr. H. C. Hayes, Head Physicist
Superintendent, Sound Division

Approved by:

H. G. Bowen, Rear Admiral, U.S.N.
Director

Distribution:
(1) SecNav
(5) Cominch (Readiness)
(5) CincPac
(5) Cinclant
(5) ComDesPac
(5) ComDelLant
(1) OpNav (23R)
(1) OpNav (DNC)
(1) BuShips (477)
(3) BuShips (340)
(1) BuOrd (Re6b)
(1) BuAero
(3) Coordinator of R.&D.
(1) NOL, Navy Yard, Wash.
(3) CO Fleet Sound School, Key West
(3) CO Fleet Sound School, San Diego, Cal.
(1) USN Radio and Sound Lab, New London
(1) USN Radio and Sound Lab, San Diego, Cal.
(1) CO Sub Base, New London
(5) O in C, Sub Chaser Training Center, Miami
(5) Com. U.S. Coast Guard
(1) Radio Materiel School, NRL
(5) U.S. Atlantic Fleet, Anti Sub Warfare Unit, Boston
(1) Naval Service Headquarters Royal Canadian Navy, Ottawa
(1) National Research Council of Canada, Ottawa
(1) BuOrd
(5) British Central Scientific Mission
(1) Com. Task Force 21
(1) Com. Task Force 22
(1) Com. Task Force 23
(1) Com. Task Force 24
(1) Com. Task Force 25
(1) C.O. USS Semmes
(1) Com. East Sea Front
(1) Com. Caribsea Front
(1) ComGulf Front
(1) ComPan Front
(2) ONI (To be forwarded to Nat. Res. Council, Halifax, Nova Scotia, Attention: J.H.L. Johnston)
(1) Naval Mine Warfare School Yorktown, Va.
(1) Chief Signal Officer, USA
(2) Naval War College
(1) U.S. Naval Attache London (Technical Section)
(1) The Captain H.M.A/S E.E., Fairlie
(1) National Research Council of Canada, Halifax, N.S.
(17) Files

jsr

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **05 NOV 1942**	2. REPORT TYPE	3. DATES COVERED **00-00-1942 to 00-00-1942**

4. TITLE AND SUBTITLE **The A-B-C's of Anti-Submarine Warfare**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,4555 Overlook Avenue SW,Washington,DC,20375-5320**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**17**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

TABLE OF CONTENTS

ABSTRACT

The present report attempts to avoid all wishful thinking that tends to blind us to the true status of our war against the U-boats. Some measure of success is attained through the application of a simple relation between the percent of U-boats that are attacked, the percent of the attacks that result in kills, and the percent of U-boats that must be destroyed to assure victory.

The conclusion is reached that we are losing the present anti-submarine war by such a large margin that measures should be immediately taken to outline, codify, and put into action a more effective anti-submarine program.

The report then presents a new anti-submarine procedure, based on this same relation between percents, for consideration as a part of the new program.

I ANALYSIS OF PRESENT SITUATION

1. This report considers the Anti-Submarine War Problem from the standpoint of two fundamental requirements for its solution. These requirements are corollary to the axiom that in all war problems dealing with offense and defense the offense fails whenever on repeated attacks its losses exceed some fairly definite percent. It follows from this self evident fact that a solution of our present anti-submarine problem calls not only for means of combating the U-boats but also for ways and means of bringing about a sufficient number of combats to raise their losses above this critical percent.

A. The Formula a.b = c

2. The nature and relation of these two necessary conditions become more clear when they are expressed mathematically. For this purpose let:-

N equal the number of U-boats that arrive, say, per month.
n equal the number of U-boats that return home per month.
a equal the percent of N that are attacked per month.
b equal the percent of attacks that are successful.
c equal the percent of N that do not return home as a result of the attacks.

Then, from definitions,

$$\frac{N-n}{N} = c \qquad (1)$$

This relation takes a form better suited to our purpose by substituting for the numerator (N-n) through the obvious relation:-

$$N-n = a.N.b \qquad (2)$$

Thereby giving

$$\frac{a.N.b}{N} = c \qquad (3)$$

Which simplifies to,

$$a.b = c \qquad (4)$$

This simple relation, which states that the percent of the U-boats that are attacked multiplied by the percent of the attacks that are successful equals the percent of the total arrivals that are destroyed, embodies the simple fundamentals - "The A-B-C's of Anti-Submarine Warfare".

3. A consideration of the graph of this equation throws some light on our present anti-submarine problem.

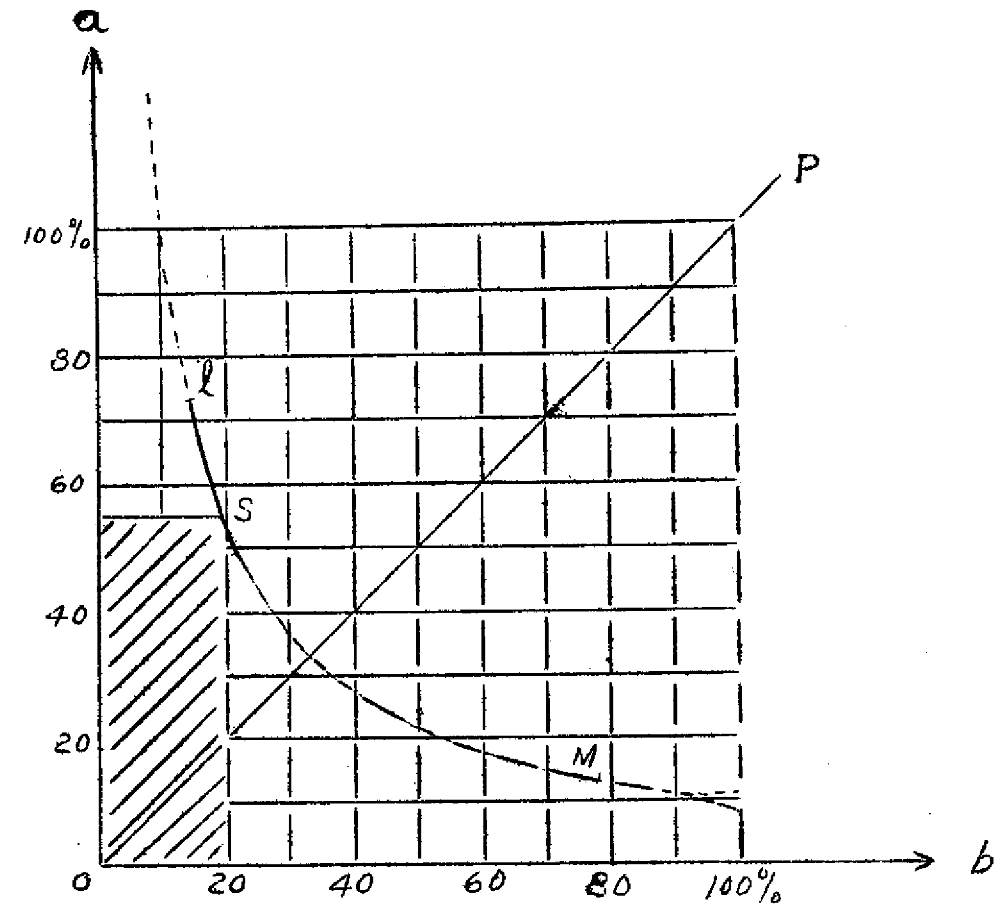

FIG. I

Figure 1 gives such a graph, wherein the ordinates represent the factor (a) - the percent of the U-boats that are attacked -, and the abscissæ represent (b) - the percent of the attacks that result in kills -, and (c), as plotted, has the arbitrary value of 11 percent. This curve - the equilateral hyperbola - is obviously symmetrical with respect to the 45 degree axis (o-p). It is characterized by the fact that the area inclosed by the coordinates of any and all points along the curve and the axes of reference is the same, and is numerically equal to (c). The cross-hatched area shows this relation for one point (s) of the curve.

4. If we apply the limits and conditions of our problem to this graph, the following general points may be noted:

a. Our a-b-c relation is an equation of percents. The maximum value of (b) or (c) is 100% or unity. Theoretically (a) is not limited, due to the possibility of repeated attacks, but practically it remains less than unity.

b. The intercept of the curve on either the 100% ordinate or abcissa equals the value of (c) and therefore the value of both (a) and (b) must exceed (c) for all other points on the curve.

c. The normal conditions of our problem are such that neither (a) nor (b) can be expected to approach very near to 100%, and as a result, the practical limits of the curve may be considered as the solid line portion lying between some such points as (l) and (m). It follows that, in practice, the factors (a) and (b) must both be considerably larger than (c) to assure defeat of the aggressor.

5. Such consideration of the a-b-c relation teaches that the percent of kills alone does not furnish a basis for estimating our progress toward solution of the U-boat problem. The measure of our anti-submarine efforts must be expressed as an area of dimensions (a) and (b) as defined. In addition it teaches that in practice the value of each of these factors must be decidedly larger than (c) to assure final success.

B. Its Application in Estimating our Present Status

6. A rough estimate of the present status of our anti U-boat efforts can be gained by deriving and substituting approximate values for factors a, b and c. Regarding the factor (c), combat statistics - and in particular those dealing with the U-boat campaign of the last war - indicate that the factor (c) must lie somewhere between 10 and 12 percent to assure victory. We take the average value of 11 percent. Regarding factor (b), British reports indicate that from 6 to 8 percent of their patrol ship attacks on U-boats have resulted in kills. Since the British have had more experience in this type of warfare than has our Navy, the average value of 7 percent for factor (b) would seem to be conservative. Finally, an average of the estimates of three experienced officers associated with the anti-submarine program gives for factor (a) a rough value of 20 percent.

7. First it becomes of interest to determine (a), the percent of the arriving U-boats that must be attacked in accordance with present procedure to assure final victory. The insertion of the values .07 and 0.11 for (b) and (c) respectively in the a-b-c relation gives:-

$$a \cdot 0.07 = 0.11$$

Wherefore: $a = 157\%$

This means that we must either attack every arriving U-boat once, and 57% of them a second time, or reach this required number by some other combination of multiple attacks. Obviously our patrol ships fall far short of making such an attack record.

8. It also becomes of interest to insert the values of 20% and 7% for (a) and (b) respectively and determine the value (c) that is given by present anti-submarine procedure. This gives for the a-b-c-relation:

$$0.20 \cdot 0.07 = c$$

Wherefore: $c = 1.4\ \%$

This means that the results of present procedure must be improved by a factor of 8 to raise (c) to the 11% value required for victory over the U-boats.

9. This picture of the present status of our anti-submarine war problem is probably somewhat overdrawn, because it neglects successful attacks made by patrol planes, blimps, and armed merchant ships. Nevertheless this gives but little grounds for comfort, because the situation still remains alarmingly unsatisfactory even when we conservatively credit to these three agencies a combined rate of U-boat sinking equal to that of the patrol ships. Under this optimistic assumption it still becomes necessary for our patrol boats to combat 80% of the arriving U-boats under present anti-submarine procedure, or else to devise and adopt some other procedure that is at least four times more effective than is the present procedure.

C. Conclusions

10. This estimate of the present status of our anti-submarine problem in the light of its broader aspects, as disclosed by the a-b-c relation, gives cause for grave concern, for it argues convincingly that the German U-boat campaign is succeeding and that our preventive measures fail by a large margin in controlling the situation. These are bitter pills. But they must be swallowed if the patient is to survive. We must clearly recognize and candidly admit that we are facing a dangerous situation that promises to become desperate before we are mentally conditioned to solve the U-boat problem once and for all, because its solution calls for such clear thinking, unstinted cooperation, and concerted action as obtain only in the admitted presence of dire peril.

11. If this estimate of the present status of our anti-U-boat war problem even approximates the truth then it would seem that the time has arrived when such clear thinking and concerted action should be forthcoming and it now becomes advisable to reassess values and to outline and put into effect a new or modified anti-submarine program that gives definite promise of success.

12. Obviously the decisions that must be made in formulating such a program are so vital and far-reaching that they cannot and must not be hurriedly conceived. They must result from discussions leading to a better understanding of the character and scope of the U-boat problem as it has unfolded to date; from a thorough analysis of all phases of our present anti-submarine program that exposes and leads to an understanding of its short comings; from a careful survey of the research and developmental programs that are underway or contemplated by all laboratories concerned, with a view to directing their efforts to best meet the requirements of our new course of action; and finally from an analysis of the present administrative set-up designed to point the way to modifications that make for better efficiency and more concerted and uniformly aggressive action.

II A PROPOSED NEW ANTI-SUBMARINE PROGRAM

13. The remainder of this report aims to outline an anti-submarine program of high promise that should be seriously considered as a part of our new course of action. This program has resulted from considerations of the various phases of the U-boat problem as long visioned by this Laboratory. It endeavors to make the most of the material at hand in the shortest possible time by requiring a minimum of new developments and by making their design such as to facilitate procurement.

A. Planes, Blimps, and Ships

14. The nature and content of this program can be understood by applying the a-b-c relation to the three types of anti-submarine craft - the patrol plane, the blimp, and the patrol ship - and comparing the results. For this purpose we express each factor in caps, small caps, or common type to indicate respectively whether its relative value is large, medium, or small.

15. Consider first the patrol plane with or without radar equipment. Its ability to scan the sea surface at a rapid rate results in its contacting more U-boats than all other agencies combined. Theoretically at least, each contact may be considered as resulting in a combat through depth bombing an area adjacent to the point where the target submerged. This procedure has, for the most part, now been abandoned because of the extremely low percent of kills. Thus the a-b-c relation for the patrol plane becomes,

$$A \cdot b = c,$$

wherein the small value of (c) results from the very low value of (b), the percent of kills.

16. The search rate of the blimp is low as compared with that of the plane but somewhat higher than that of the patrol ship because of its higher speed and greater radar range. Its percent of kills, however, must be very low because it can be seen by the target long before it can attack, and because it has no effective means of attacking a submerged target. The a-b-c relation applied to the blimp thus becomes,

$$\textsc{a} \cdot b = c$$

wherein the very low value of (c) is due primarily to the low value of (b) although the relatively low value of ($\textsc{a}$) is contributory.

17. Finally a consideration of the patrol ship leads definitely to the conclusion that its searching rate both by sound and radar is

inherently low because of its relatively slow speed and short detecting range. Its percent of attacks, factor (a), must therefore be relatively low. Its percent of kills, factor (b), however, is relatively high due to its ability to carry out a directed underwater attack. Thus, the a-b-c relation applied to the patrol ship becomes,

$$a \cdot B = c$$

where the intermediate value of (c) results from the relatively large value of (B) as compared with other types of craft.

18. Assembling these three relations for purposes of comparison gives:-

$A \cdot b = c$ for patrol planes
$A \cdot b = c$ for blimps, and
$a \cdot B = c$ for patrol ships

Bearing in mind that the solution of our problem depends primarily on finding an anti-submarine procedure that yields the maximum value of (c), a consideration of these three equations leads to the conclusion that a cooperative search and attack program between patrol planes and patrol ships is the answer, if ways and means can be provided whereby a patrol plane can persistently follow and finally direct an arriving patrol ship to sound contact with the U-boats that it surprises and forces to submerge.

19. Our new course of action might well insist on such cooperative tactics between patrol planes and ships, and to that end exert such directive pressure as may be necessary to provide the required ways and means. The nature and present status of such ways and means will be considered later.

B. <u>Factor (B) vs. Factor (t)</u>

20. Next it becomes desirable to improve the factor (B) for patrol ships which, though large as compared with the value given by aircraft, is still too small by a factor of at least 4 to assure a prompt solution of our problem. The way to such improvement becomes clear when we recognize that this factor bears an inverse relation to the potential escape area of the target. The nature of this area (E), as shown in Figure 2, is well understood as to form, but its area is not so generally known. The area (E) of this figure is best expressed for our purpose as:-

$$E = \frac{(V \cdot t)^3}{3r} = \frac{V^3}{3r} \cdot t^3 \qquad (5)$$

where r, V, and t represent respectively the turning radius of the target, the velocity of the target, and the time elapse between the start of laying the depth charge pattern and its arrival at the depth level of the target. This is an unusual relation, since areas are usually proportional to the second power of distances. This represents an area as proportional to the third power of the target's escape distance (V.t). A large time factor is thus very favorable to the target, whereas any reduction of this factor has an unexpectedly large effect in reducing its possible escape area.

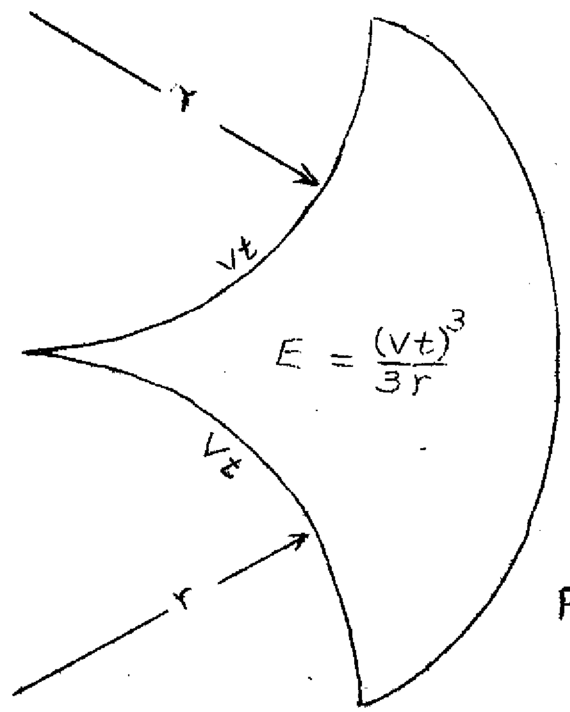

FIG. 2

21. Since the factor (B) is inversely proportional to (E) and since the factors (V) and (r) are beyond our control, it follows that our control over (B) lies wholly in our control over (t), and that (B) becomes a maximum when (t) is reduced to a minimum. Moreover, there is every incentive to strive for an absolute minimum value of (t) because it operates as (t^3) and every increment of reduction nets a relatively large increase in factor (B), the percent of kills.

22. Obviously (t) becomes an absolute minimum when the bomb pattern is laid about a point directly over the target and the bombs are designed to give the maximum practical velocity of fall. Such a procedure requires that the attacking ship shall take a collision course directed by sound bearings on the target.

C. The Direct Attack

23. Tests on two types of patrol ships, the destroyer NOA, references (c) and (d), and the PC-451, reference (f), have proved this so called Direct Attack procedure, references (a) and (e), to be practical and readily executed with the aid of standard sound equipment so long as the target operates near the surface. But since the nature of the Direct Attack is such as to encourage the target to submerge as deeply as safety factors permit, its proper execution calls for a projector that can be measurably tilted downward at the will of the sound operator.

24. Recognition of the advantage to be gained by reduction of the time interval (t) between the start of launching the bomb pattern and its arrival at the depth level of the target has led to development of the so called "Hedgehog" by the British and of a modification thereof by NDRC termed the "Mouse Trap". Both devices abandon the slow sinking "ash can" in favor of a small streamlined contact bomb having a terminal velocity of about 25 feet per second, and both project these bombs from the point of departure to a predetermined pattern about a predicted attack point some 300 yards ahead. It becomes a matter of interest to compare the relative value of the percent of kills, factor (b), as determined by these improvements over present attack procedures with that which can be attained by the use of our recommended Direct Attack.

25. Such a comparison must, for completeness, take into consideration: - (a) the form, dimensions and bomb spacing of the barrage, (b) the error in positioning the center of the barrage relative to the target, and (c) the potential escape area of the target. Since the Direct Attack can employ a bomb pattern practically identical with that employed by either the "Hedgehog" or the "Mouse Trap" our comparison, in the interest of simplicity, will assume like barrages - though this definitely favors the "Mouse Trap" since the Direct Attack normally would employ a more effective pattern. Also it will assume equal accuracy in positioning the barrage with respect to the target - although the error in locating the target from the firing position of the "Hedgehog" or "Mouse Trap" barrage is inherently greater than from the Direct Attack position over the target. Therefore, it may be noted that the following comparison, which considers only the relative potential escape areas, does not measure the full superiority of the Direct Attack.

26. Employing the subscripts (m) and (d) to indicate that a factor pertains respectively to the "Mouse Trap" and "Hedgehog" or to the Direct Attack we find the following relations:-

$$t_m = 8 + H/V_m \qquad (6)$$

$$t_d = H/V_d \qquad (7)$$

where 8 is the test flight time of the "Mouse Trap" bombs, (H) is the depth of the target, V_m and V_d are respectively the sinking velocity of the "Mouse Trap" and the Direct Attack bombs, and t_m and t_d are respectively the two time intervals. Their ratio becomes

$$\frac{t_m}{t_d} = \frac{V_d}{V_m} \cdot \frac{8V_m + H}{H}$$

Inserting numerical values as follows:-

$$V_d = 40 \text{ feet per second}$$
$$V_m = 25 \text{ feet per second}$$
$$H = 200 \text{ feet}$$

we find

$$\frac{t_m}{t_d} = \frac{40}{25} \cdot \frac{8 . 25 + 200}{200} = \frac{80}{25} = 3.2$$

Wherefore:

$$t_m = 3.2 \; t_d$$

It follows from the reasoning of paragraph 20 that the Direct Attack promises the larger percent of kills, factor (b), even when its bomb pattern is restricted to a form that is less effective than others which normally would be employed and its inherently greater accuracy in locating the pattern is neglected.

27. Our new course of action might well insist on the adoption of the Direct Attack as standard procedure, and to that end bring such pressure to bear as may be necessary to provide the required ways and means.

D. Ways and Means

28. The nature and present status of the ways and means required to make the above recommended anti-U-boat program practical will now be considered.

1) For Plane-Ship Cooperation

29. First we consider the various possibilities that can aid one or more patrol planes to direct a patrol ship to sound contact with a U-boat that has been contacted and forced to submerge. Since the opacity and electrical conductivity of sea water are such as to prohibit the use of light or radio for following the movements of a submerged target, such information must be gained through detection of its distortion of the earth's magnetic field, or through submarine sounds emanating directly from its propellers and auxiliaries, or reflected from its hull.

30. Development of the magnetic detector has been carried to a high degree of perfection by NDRC. The type MAD is well designed for use on patrol planes, where it is reported to have located a wrecked hull to

a range of about 500 feet. While this fact alone gives no assurance that a plane equipped with MAD can follow the movements of a deeply submerged U-boat with any degree of certainty, it at least raises the hope that a MAD can be developed to do this if tests prove that the target can escape this device in its present form. Certainly the magnetic detector offers definite advantage over the acoustic detector for the subject purpose, since it permits the plane to remain in the air.

31. Here, then, is one definite directive for technical development. Neither cost nor research effort should be spared in the search for magnetic means whereby a patrol plane can successfully follow the movements of a submerged submarine.

32. The Naval Research Laboratory has developed a simple, lightweight underwater sound and echo detector for use on patrol planes to serve the subject purpose, but thus far no opportunity has been offered to test it on a plane. Tests on a small coast guard cutter, however, have given surprisingly favorable results. Propeller sounds of surface ships were heard in both the audible and supersonic frequencies to ranges up to 3000 yards, and clear echoes from a submarine were heard up to 1500 yards. This device mounts in a 10" well, and weighs about 50 lbs. When not in use it can be withdrawn from the well and stowed, and the well closed by a screw cap. It requires relatively little power to operate because, like radar, it employs the discharge of a condenser to generate a very short but also an intense signal. A six volt 100 ampere-hour storage battery with a small generator serves to operate the device for about 24 hours.

33. In addition to the simple hull-mounted device described, the NRL is well along in the development of an echo and sound detection equipment that can be towed from either a blimp, a small patrol boat, or a surfaced plane. This "fish" gives promise of serving the subject purpose even better than the small hull-mounted unit, since the orientation of its sound beam is much less affected by the excessive roll and pitch inherent in small surface craft of almost any type.

It will therefore be seen that acoustic equipment that promises to enable a surfaced patrol plane to hold sound contact with a U-boat is already at hand and that new designs of considerable promise are nearing completion. Thus there is no call for any extended research and developmental underwater sound program directed to the subject purpose.

2) <u>For Direct Attack</u>

35. The ways and means required to execute the Direct Attack naturally fall into two groups, (a) and (b), as follows:-

a. Underwater sound detecting equipment capable of directing the attacking ship along a collision course with, and of indicating the instant of passing over, a submerged U-boat.
b. High speed depth bombs carrying contact or close proximity fuses, and means for projecting these bombs by remote control

from the bridge into a pattern of such area and dimensions that the target cannot escape from underneath.

Obviously the responsibility for developing and procuring the requirements falling within group (a) rests with the Bureau of Ships and those falling within group (b) rests with the Bureau of Ordnance.

a) Acoustic

36. The NRL, acting under directives from the Chief of the Bureau of Ships, has developed and successfully tested on the USS NOA, references (c) and (d), and USS PC-451, reference (f), sound detecting equipments that meet the acoustical requirements of the Direct Attack. It may therefore be noted that execution of the Direct Attack also calls for no extensive research and developmental program so far as underwater sound and echo detection is concerned.

b) High-Speed Bombs and Projectors

37. The high speed bombs and projecting equipment required for executing the Direct Attack, references (a) and (e), are however almost entirely lacking. Development of projecting equipment suitable for the subject purpose has not been started, and much remains to be done before suitable bombs are forthcoming. One type of bomb designed by NDRC for terminal velocity of from 32 to 35 feet per second has been tested by Ordnance and rejected for lack of a reliable contact fuse. Meantime the development of both proximity and contact fuses which promise to serve for these bombs is under way at the Naval Ordnance Laboratory. But a bomb speed of 35 feet per second is too slow to give the Direct Attack full effectiveness. A theoretical study of the fall of bombs in sea water made by this Laboratory - reference (b) - and tests of bomb models made by NDRC, both indicate that terminal speeds approximating 50 feet per second are practical.

38. Here, then, we find another clear directive for concentrated research and developmental effort. The projecting means might well be developed into a reasonably light and compact form designed to mount along the ship's rail in such numbers as the nature of the ship permits. Since the Direct Attack procedure is applicable to any type of patrol ship, the projecting means should be designed accordingly. The high speed projectiles should first be developed to a form giving the highest practical terminal velocity under the action of gravity alone. The scope of the bomb problem, however, should cover the possible use of propellants for increasing the terminal velocity to still higher limits.

39. The possibilities of the "super speed" bomb for use in the Direct Attack become clear when it is remembered that this attack procedure can be made to locate accurately a point directly over the target, even under rough sea conditions, by a gyro-stabilizer for the projector or possibly by a well designed gimbal mount, and that a single vertically directed super speed bomb then has a fair chance of contacting

the relatively slow moving target. A patrol ship equipped to locate accurately a point directly over the target and simultaneously to project a pattern of four or five such bombs from vertical tubes mounted through the hull offers sufficient promise of raising the percent of kills, factor (b), to such practical values as would warrant a concentrated research and developmental program directed to this end.

40. Our new course of action might well embrace such a research program with the understanding that it should be prosecuted to the limit, and that the design of the patrol ship itself, which is an important cooperating part of the anti-submarine equipment, should fall within its scope. Meantime, it may be noted that evan a relatively small patrol boat can carry such equipment and still leave a clear deck.

3) For Evaluating Anti-Submarine Research Programs

41. Thus far a consideration of the a-b-c relation has pointed the way to a promising anti-submarine program and has indicated certain research and developmental objectives that merit more concentrated and intensive prosecution. It will be seen that it can also serve to appraise the relative importance of the numerous and varied research and developmental anti-submarine programs that are under way or contemplated by estimating their effect on factors (a) and (b).

42. Consider first any and all developments designed to effect improvements over the underwater sound detecting and ranging equipment of patrol ships that are already at hand. This includes the SLG gear that has recently been recommended as a part of the QC equipment and the several types of scopes that are in process of development. Their purpose is to improve the present low percent of kills - our factor (b). But analysis, reference (e) shows that this low percent is due primarily to the nature of the indirect attack procedure and not to shortcomings of the present sound equipment. Moreover, somewhat exhaustive tests - references (c), (d), and (f) - have shown that sound equipment already perfected and in use meets the requirements of the Direct Attack, and there is reason to believe that it can serve well for directing both the Hedgehog and Mouse Trap modes of attack. Therefore, the most that can be hoped for from a continuation of such developments is some relatively small increase in the factor (b). They contribute nothing to the factor (a), since they do not improve the range of detection.

43. Finally we consider all forms and types of Plan Position Indicators. Their purpose is to direct the attacking ship's course toward a predicted point ahead of the target. Our analysis, references (a) and (e), shows that the target, under present attack procedure, may be located at any point in a potential escape area that is large with respect to the area of a practical bomb pattern. It may therefore be expected that any development that serves to locate accurately a depth charge pattern at this predicted point will eventually improve the target's chances of escape, since this will become the one place for the target to avoid. It follows that the Plan Position Indicator, which is intended to increase the percentage of kills (b) under present procedure, may well work to decrease its value. Moreover, if, as appears probable, present

attack procedure is abandoned in favor of some form that permits the attacking ship to proceed along a collision course with the target, then the Plan Position Indicator is not required.

44. Thus it appears that a considerable portion of our anti-submarine research and developmental efforts could be directed to better purpose. A slight improvement in factors entering into our U-boat offensive that already serve their purpose reasonably well can never effect the 8 fold improvement that appears to be necessary. Such a degree of improvement must be sought through development of ways and means of strengthening the weak points and not the strong points of this offensive. The weak points, as stated herein and covered more fully in references (a) and (c), are inherent in the Indirect Attack procedure, which permits the target too much time to employ evasive tactics. Therefore, improvement must be expected primarily through the development of ways and means of reducing the present inordinately long escape interval. The portion of our present research efforts that is definitely directed to this end is far to small.

III SUMMARY

45. Summarizing briefly, this report attempts to assess our present anti-U-boat program and thereby reach a conclusion as to how much, if at all, its effectiveness must be enhanced to assure victory. This is accomplished through the development and application of a simple mathematical relation between the percent of U-boats attacked, the percent of attacks that result in kills, and the percent of U-boats that are destroyed. The conclusion is reached that we are definitely losing our war with the U-boats, and that in order to win, our present offense must be strengthened by a factor of at least 8. This mathematical relation is further employed to define a new anti-U-boat program and procedure that promises sufficient improvement to turn failure into success.

REFERENCES

a) NRL Report No. S-1776 - "Analysis of Methods and Means of Anti-Submarine Attack". 27 August 1941

b) NRL Report No. S-1803 - "A Theoretical Study of the Speed of Fall of Depth Charges in Water." 6 November 1942

c) NRL ltr. C-A16-3(21) dated June 9, 1942 to BuShips

d) NRL ltr. C-S16-3(21) dated June 24, 1942 to BuShips

e) NRL Report No. S-1908 - "Report on an Analysis of the Anti-Submarine Warfare Problem from the Standpoint of Underwater Acoustics". 17 July 1942

f) Enclosure to NRL ltr. C-S68/89 (220) dated 16 Sept. 1942 to BuShips.